Skills, Flexible Manufacturing Technology, and Work Organization

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This study employs a national survey of over 3000 U.S. manufacturing establishments to explore associations between worker skill requirements and use of production and telecommunications technologies, work organization, and other management practices. Ordered probit equations show an empirical link between increases in each of six types of skill requirements, as reported by plant managers, and the use of flexible technologies and work organization practices. Technology use is most strongly linked to computer skill requirements. Work organization practices were strongly associated with problem-solving and interpersonal skill increases, suggesting that new work organization practices are broadening the set of skills sought by manufacturers. Traditional academic skills (e.g., math and reading) also were linked to the use of flexible technologies and work organization practices, but increases in these skill requirements were reported less frequently than were requirements for computer, interpersonal, and problem-solving skills.

FUNDAMENTAL CHANGES IN THE WAY U.S. BUSINESSES OPERATE HAVE RAISED CONCERNS among education, labor, business, and government leaders about whether high school graduates are adequately prepared for jobs in today's economy. Murnane and Levy (1996), for example, describe how production and clerical jobs have evolved from specialized tasks

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with little decision-making responsibility to more broadly defined jobs where workers must be able to perform multiple tasks, work in teams, perform quality inspections, and solve semistructured problems. Murnane and Levy argue that these new responsibilities have created a demand for "new basic skills" that high school–educated workers need to earn a middle-class wage. The new basic skills are a suite of different types of skills comprised of "hard skills" (i.e., basic mathematics, reading, and problem solving), "soft skills" (i.e., communication and the ability to work in groups), and "computer skills." Other authors, notably Applebaum and Batt (1994), have described similar sets of skills required by new management and production methods.

It is widely believed that changing skill demands are behind important labor market phenomena such as earnings inequality. For instance, analyses by Bartel and Sicherman (1999) and Juhn, Murphy, and Pierce (1993) identify the principal source of earnings inequality among production workers as "unobservable skill." This conclusion leaves unanswered a critical policy question: "What, in fact, are the skills needed to fulfill the requirements of the modern workplace?" Knowledge about how these skills are growing and what factors are promoting their growth is essential before inadequacies in education and training policies can be addressed. Deficiencies in general worker skills also could prove to be a bottleneck in the modernization of U.S. manufacturing establishments (Finegold 1991; Cappelli 1996; Howell and Wolff 1992).

Despite the importance of these questions, Murnane, Willett, and Levy's (1995:251) observation that ". . . quantitative research has provided few clues about what skills might be in growing demand" still holds true. Case studies have done much to provide insight, but the results may not be generalizable (Osterman 1995). Studies of the mix of skilled and unskilled workers (Berman, Bound, and Griliches 1994; Doms, Dunne, and Troske 1997) and skilled-unskilled wage differentials (Johnson 1997) suggest increasing skill requirements associated with technology. These studies have focused generally on the use of computers and related technologies and emphasize computer and academic skills, ignoring soft skills. Other studies have focused more on work-organization effects on skill. Several studies have used unidimensional skill measures or proxies for skill, usually the incidence of training, to show that new forms of work organization are associated with increased skill requirements (Cappelli 1996; Osterman 1995; Frazis, Herz, and Horrigan 1995; Leigh and Gifford 1999). However, the work of authors such as Applebaum and Batt (1994), Howell and Wolff (1992), Murnane and Levy (1996), and Park (1996) shows that an important aspect of changing skill demand is the requirement for a complementary set of skills. Thus multidimensional measures of skill are needed to give a more complete description of changing skill requirements (Spenner 1983).

This article uses a new national survey of manufacturing establishments to investigate how reported increases in six types of skill requirements are correlated with a broad range of production technologies, work organizations, and other management practices that characterize flexible manufacturing. Our survey data and our approach are similar to those used by Cappelli (1996), but our study uses a multidimensional skill measure and considers a broader variety of technologies and management practices. Our survey includes more than 3000 employers' assessments of growth in six types of skill requirements that roughly correspond to Murnane and Levy's new basic skills. Our multidimensional measure of skill provides insight about which types of skills are growing most rapidly and how these skills are linked to production processes. We estimate statistical models to empirically establish the link between each skill type and the use of flexible production technologies, work organizations, and other management practices. This provides more insight about how new practices affect skill requirements and may uncover some effects that are hidden when using a generic skill measure. We are able to hold constant basic establishment characteristics, such as size, unionization, education, and the expected skill intensity of the workforce in multivariate analysis. Our study provides generalizable results that complement previous case studies.

The article begins with a discussion of issues related to measurement of skill, technology, and work organization. We then describe the data and provide a descriptive analysis of increases in skill requirements, the prevalence of various technologies and work-organization practices, and their correlation with skill growth. Next we describe the results of ordered probit models that identify associations between growth in each of the six skill types and the various technologies and practices for which we have information. Finally, we provide concluding comments.

New Technologies, Management Practices, and Skills

Fordist mass production sought to exploit economies of scale achieved through producing large lots of identical products. In contrast, flexible manufacturers seek to make products in small batches tailored to the needs of highly differentiated market niches using strategies labeled variously as *lean* production, *agile* manufacturing, *mass customization*, or *flexible specialization* (Klier 1993; Milgrom and Roberts 1990; Piore and

Sabel 1984; Scott 1988; Dohse, Jurgens, and Malsch 1985). Adoption of computerized equipment for automation and communications in production operations has done much to make this possible (Zuboff 1988:390; Baldwin, Diverty, and Sabourin 1995). Communications technologies facilitate the sending and receiving of orders and technical data between departments within a plant and communication with external entities, including headquarters, customers, and suppliers. It is widely believed that use of computers and other advanced equipment in production operations boosts the required level of technical knowledge, skill in using computers, and basic numeracy needed to operate such equipment.[1]

Much of the economics literature has focused on complementarity between computer technology and skill. However, a broader definition of flexible manufacturing incorporates changes in the way workers do their jobs and the management of firms and their linkages with other plants and firms (Kochan, Cutcher-Gershenfeld, and MacDuffie 1993). A number of authors have studied *high-performance* or *transformed* work-organization methods that encourage workers to become adept at multiple tasks, work in teams, and take responsibility for quality control (Osterman 1994; Applebaum and Batt 1994; Cappelli 1996; Park 1996). Flexible work-organization techniques include job rotation, work teams, quality circles, and employee problem-solving groups. Just-in-time, statistical process control, total quality management, and small-batch production also have been integral to flexible manufacturing (Cappelli 1996; Linge 1991; Klier 1993). These practices are commonly associated with managerial and administrative work, but greater interconnectivity with customers or suppliers via telecommunications technology, the nature of marketing strategies, and external relations with other firms are likely to affect the work process on the shop floor as well. For example, shorter, customized production runs that feature noncost attributes such as design, delivery, and quality often are accomplished by the combination of general-purpose machinery with more skilled workers (Piore and Sabel 1984). Flexible approaches to manufacturing often are based on the notion of continuous improvement, which is in turn founded on concepts of giving workers greater autonomy, building quality control into the production process, and treating work as a system (Applebaum and

[1] While economists generally have assumed that new technology and skilled workers are complementary, other social scientists have debated whether new technology upgrades or downgrades skill requirements by eliminating traditional craft skills, resulting in polarization between increasingly sophisticated technical and low-skilled production work (Keefe 1991). A third, "mixed effects" view has emerged in which tendencies for upgrading or downgrading of skills are conditioned by a large set of firm-specific variables that may result in little net change in skill demand (Spenner 1983).

Batt 1994). Sabel (1996) outlined an emerging mode of decentralized coordination in manufacturing design and production premised on the dual functions of monitoring and learning where cooperating parties (e.g., autonomous work groups within a firm) assess actual performance and discuss ways of improving operations in light of their joint assessment. This model of manufacturing emphasizes contextual knowledge of work in contrast to the detailed technical knowledge characteristic of craft work. New forms of flexible or decentralized work organization may give production workers greater responsibilities and require them to work in groups, increasing the importance of interpersonal skills, group decision making, and the ability to identify and solve problems.

A recent study by Bresnahan, Brynjolfsson, and Hitt (1999) suggests that "new organizational forms which favor increased lateral communication and coordination" are required to fully exploit the value of information technology (IT) to the firm (Bresnahan, Brynjolfsson, and Hitt 1999:15). This, in turn, reinforces the demand for more skilled workers beyond the widely acknowledged substitutability of IT for many low-skill tasks while being a complement to higher-skill analytic tasks. As a "broad brush" empirical analysis, the associations identified are consistent with IT investment, human capital, and decentralized work organization as complements posited in their model of organizational change. The article by Bresnahan, Brynjolfsson, and Hitt forces one to reconsider the definition of *technological change* because their analysis suggests that greater use of IT, if not combined with new forms of decentralized work organization, has no discernible impact on improved productivity. Thus new forms of work organization and related practices also should be considered important changes in "technology" that may be skill-biased. In addition, different types of practices used in a workplace may affect demands for different types of skills.

Like the study by Bresnahan, Brynjolfsson, and Hitt, this study examines the association between demand for skill, computer use, and new forms of decentralized work organization. However, we are able to explicitly analyze the types of skills required of manufacturing production workers. Bresnahan, Brynjolfsson, and Hitt, like many previous researchers, relied on traditional categorical (i.e., broad occupational class) and indirect (i.e., educational attainment) measures of skill, assuming rather than testing increased requirements of specific skills. The identification of specific skills in our analysis can help guide educational policy and inform the training practices of firms initiating organizational and technological change.

In this article we investigate how various flexible manufacturing practices are associated with different dimensions of job skill requirements for production workers. Following Cappelli (1996), we hypothesize that change in skill requirements can be modeled as a function of technology, work organization, and other current establishment characteristics. We assume that skill is not a generic characteristic but rather a multidimensional concept composed of a set of distinct types of skills. We hypothesize that the composition of the skill vector varies depending on the types of practices used in the workplace. For example, establishments employing advanced technology may place greater emphasis on computer skill requirements relative to interpersonal skill requirements. Conversely, establishments using work teams may have greater demands for interpersonal than computer skill requirements.

We specify an empirical model for the *j*th skill in the *k*th establishment,

$$s_{jk} = X\beta_{jk} + e_{jk} \quad j = 1, \ldots, 6 \tag{1}$$

where s_{jk} represents change in one of a set of six skill requirements, X_k is a vector of technologies, management practices, and other establishment characteristics, β_j is a vector of coefficients, and e_{jk} is a stochastic error term. We anticipate that $\beta_j > 0$ for most technologies and management practices, but some practices may not affect all skills. We are interested in comparing both the signs and magnitudes of the elements of β_j within and across equations to gain insight about relationships between various practices and dimensions of skill.

As Cappelli (1996) points out, it would be preferable to have changes in establishment practices on the right-hand side of the equation to explain *changes* in skill, but our survey only provides information on the contemporaneous *use* of practices. Most of the work-organization and telecommunications practices we consider in this study are new enough that they would have been adopted fairly recently. Some of the production technologies have been available for some years and may not have been adopted recently. Since the independent variables provide no information on the time of adoption, the results should be defined strictly as the association between increasing skill requirements and the use of various technologies or management practices. Unfortunately, we are unable to determine whether a positive effect is related to continuous use or recent adoption of a technology or practice.

The Data

The 1996 Rural Manufacturing Survey, conducted by the U.S. Department of Agriculture and Washington State University, provides a rare opportunity to explore relationships between various technologies, management practices, and worker skill demands. This nationally representative establishment-level survey was conducted to obtain information about barriers to competitiveness faced by rural businesses, but a large sample of urban establishments also was surveyed. Respondents were asked about a wide range of issues, including their use of production and communications technologies, management practices, problems they face, characteristics of their workforces, and methods of financing. They also were asked a number of questions about labor force issues, including worker skill requirements. Basic plant characteristics (e.g., number of employees, firm size, and standard industrial classification), type of production (e.g., small or large batch, custom production, or other method), and the size and composition of the workforce also were included in the survey.

A stratified sample of manufacturing establishments with at least 10 employees was chosen from a national list provided by a private vendor. The U.S. Bureau of the Census *County Business Patterns* data for 1996 indicate that establishments with 10 or more employees accounted for about half of all manufacturing establishments. However, these establishments accounted for over 96 percent of all manufacturing employment in 1996. Thus, while the survey does not cover the large number of very small establishments with fewer than 10 employees, the sample is representative of establishments that account for most manufacturing employment. In fact, few previous surveys with a national scope have sampled small establishments with as few as 10 employees.[2] Stratification of the sample was based on metropolitan-nonmetropolitan location, nonmetropolitan west-nonwest, and three employment size classes.

Our survey used a mixed-mode interview method. Establishments received mail questionnaires followed up by telephone interviews.[3] Data

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[2] For example, comprehensive surveys by the Census Bureau, the National Establishment Survey, and the Surveys of Manufacturing Technology sampled establishments with 20 or more employees, and Osterman's (1994, 1995, 1998) survey was limited to establishments with 50 or more employees.

[3] The interviewer asked who, at that location, was most knowledgeable about the broad range of issues addressed in the questionnaire. About two-thirds of target respondents were either a head of the organization or the general/plant manager. In branch plants, more than half the target respondents were heads of production, whereas in headquarters establishments, the largest number of respondents were heads of the organization. Human resources directors and financial and administrative officers responded in a significant number of establishments.

were obtained from 2800 establishments in nonmetropolitan counties and 1100 metropolitan establishments. The response rate was 68 percent. Respondents represented about 7.5 percent of nonmetropolitan and 0.7 percent of metropolitan manufacturing establishments. Comparisons have shown little difference in characteristics of metropolitan and nonmetropolitan establishments in the sample, and survey results were representative of all U.S. manufacturing establishments (Gale et al. 1999). Sample weights were developed for use in statistical analysis such that weighted establishment numbers reflect the actual number of establishments reported in the U.S. Bureau of the Census *County Business Patterns, 1994*.[4]

Skill Measures

Many approaches have been used to measure or proxy skill, and these have been surveyed elsewhere (Cappelli 1993; 1996; Howell and Wolff 1992; Spenner 1983). Our data contain a survey-based measure of employers' perceptions of change in six skill requirements over the preceding 3 years, similar to one included in the National Establishment Survey analyzed by Cappelli (1996). The six skill requirements were basic reading, math, problem-solving, interpersonal/teamwork, computer, and other technical skills. The specific wording of the question in our survey was

> Next, please think about the skills required for PRODUCTION WORKERS to perform their jobs at an acceptable level. For each type of skill, please tell whether the production job requirements for this skill INCREASED A LOT, INCREASED A LITTLE, STAYED THE SAME, or DECREASED in THE LAST 3 YEARS.

Survey respondents were asked to choose one of these four answers or "Don't know" to describe the increase in requirements. Our measure is subject to the same criticisms that Cappelli acknowledges. As a self-reported measure, the interpretations of what various skills are and the criteria for judging whether a skill increased may have varied across individual respondents. However, this variable offers the advantage of being a direct, establishment-level measure of six different dimensions of skill. We evaluated the validity of our skill measure by comparing the self-reported increases in skill requirements with the increase in training

[4] This was the most recent edition of *County Business Patterns* available at the time. Gale et al. (1999) report in more detail on statistical issues concerning the survey and report that the data were representative of national statistics on business establishments.

offered by the firm and found a strong positive correlation. Since firms reporting skill increases are also increasing training, we have confidence that the self-reported skill measure approximates actual increases in skill requirements.[5]

Table 1 summarizes responses to each of the six skill requirement questions. As Teixeira (1998) reported, most employers said that skill requirements were growing. Very few reported decreases. Growth commonly was reported for each of the six skills, but increases in computer skill requirements were reported most frequently. Thirty-eight percent of employers said computer skill requirements "increased a lot," and 29 percent said they "increased a little." Only 28 percent said computer skill requirements "stayed the same," and 1 percent said they "decreased." Increase in interpersonal/teamwork ("soft") skill requirements were reported second most frequently. One-third said that this requirement "increased a lot." Problem-solving skills were the third most frequently cited (28 percent said "increased a lot"). Increases in the other three skills were reported less frequently. More than half the respondents said that requirements for "other technical skills" increased, but a majority of respondents said that reading and math skill requirements stayed the same. However, a significant minority (15 percent) said reading and math skill requirements "increased a lot." Demands for math skills appear to have increased somewhat more than reading skills.

TABLE 1

ESTABLISHMENTS REPORTING INCREASED SKILL REQUIREMENTS FOR MANUFACTURING PRODUCTION WORKERS

Skill	Increased a Lot (%)	Increased a Little (%)	Stayed the Same (%)	Decreased (%)
Computer	38	29	28	1
Interpersonal/teamwork	33	28	37	1
Problem solving	28	33	36	2
Other technical	17	37	43	1
Basic math	15	29	53	2
Basic reading	14	22	62	1

SOURCE: 1996 Rural Manufacturing Survey (Gale et al.) weighted for sample stratification. "Don't know" responses are not shown in the table.

[5] Seventy percent of establishments that reported increases in each of six skill requirements offered training in 1996 compared with 27 percent of establishments that reported no increase in skill requirements.

Use of Technologies and Management Practices

Our survey included questions on the use of five production technologies, five work-organization practices, six telecommunications technologies, involvement in just-in-time (JIT), and mode of production (i.e., small batch, large batch, custom, or other mode). The technologies included computer-assisted design or engineering (CAD), CAD linked to computer-assisted machining (CAD/CAM), numerically controlled (NC) or computer-controlled (CC) machines, programmable controllers (PCs), and local-area computer networks (LANs). These categories are a subset of the technologies asked about in surveys of manufacturing technology carried out by the U.S. Census Bureau (Doms, Dunne, and Troske 1997) and Statistics Canada (Baldwin, Gray, and Johnson 1995). The survey included technologies with fairly general application to make the questionnaire relevant for the wide range of manufacturing industries covered. The following work-organization practices were included: self-directed or self-managed work teams, job rotation, employee problem-solving groups or quality circles (PSGs/QCs), total quality management (TQM), and statistical process control (SPC). The first four practices were included in the survey analyzed by Osterman (1994, 1998).

Respondents were asked whether they used each of these 10 technologies/practices and the percentage of production workers using them. Thus we have both a discrete measure and a measure of penetration (also used in the National Establishment Survey). For other practices, we only had discrete yes/no measures of use. Respondents were asked to identify whether they used each of six telecommunications technologies, including fax machines, modems, Internet, satellite communications, computer linkages to other firms, and computer linkages to other locations in the same firm. They also were asked whether they used a JIT inventory and production system and whether they acted as a supplier for any other establishments using JIT. Mode of production was identified as one of four choices: "Custom produce or make single units of product for each customer," "Produce small batches or limited numbers of a distinct product," "Produce large numbers of the same product," or "Other."[6]

[6] The great majority of responses in the "Other" category indicated that an even split between two or three of the options did not allow a definitive characterization as "small batch," "custom," or "large batch." A number of alternative interpretations of this response are plausible. These plants could be in a long-run transition from one mode to another; through patent, exclusive contract or by the capture of a specialized market, these plants may have been able to secure stable demand for one or more product lines that justifies a mass-production strategy; or general-purpose machinery may, at times, be apportioned to long production runs.

One of the issues that must be addressed is how to summarize this information in an aggregate measure of technology and management practice use. Several previous authors have used counts of the number of advanced practices used (Doms, Dunne, and Troske 1997; Baldwin, Diverty, and Sabourin 1995). Osterman (1994) noted that numerous definitions of high-performance work organizations (HPWOs) have appeared in the literature and no particular combination of practices has emerged as the definitive HPWO. Since no single measure has emerged from the literature, we explored the extent of technology and management practice use with both discrete use/nonuse and penetration rates for 10 practices in Table 2. The first column shows the percentage of plants that reported using each technology/practice. The second and third columns show two penetration measures: the percentage of plants with at least 50 percent of production workers and the percentage of plants with 100 percent of production workers using each practice/technology. In addition, the table provides statistics on the number of firms reporting multiple practices/ technologies (1–5) for each category of use. The use rates of production technologies and management practices generally were similar to those found in other research. Differences can be attributed to survey year, sampling frame, and the definition of survey questions.[7]

Discrete use rates of production technologies ranged from 22.6 percent of plants for CAD/CAM to 51.1 percent for NC/CC. Discrete use rates for work organization practices were somewhat higher. The least-used practice was SPC, used by 35.2 percent of plants. Use rates of the other four practices ranged from 42.8 percent for TQM to 53.7 percent for job rotation.

Penetration rates show that work-organization practices were used more widely by production workers than were technologies. Roughly 30 percent

[7] Usage rates of production technologies were similar to those reported by the 1993 Survey of Manufacturing Technology (U.S. Bureau of the Census 1994:Table 2A), although use of CAD was reported less frequently and use of programmable controllers was reported more frequently in this survey. The Survey of Manufacturing Technology was limited to several broad metalworking and equipment-manufacturing industries, whereas the current survey covers all manufacturing industries. Usage rates for management practices were very similar to those reported in Osterman's (1994) study that employed 1992 data but less than rates found in Osterman's more recent (1998) study that used 1997 data. Our measure differs from Osterman's in two important ways: Our 50 percent employee participation refers only to "production workers" (Osterman's "blue collar workers"). In our survey data, *production workers* was defined for the respondent to include "workers involved in the actual fabrication or assembly of product and their factory floor supervisors." It excluded other managerial, professional, technical, sales, and clerical workers who made up more than half of Osterman's "core workers." Our survey also included a fifth practice, statistical process control, in addition to the four practices in Osterman's National Establishment Survey data. Adjusting for differences in the sample (Osterman's sample included establishments with 50 or more employees) did not change the results appreciably.

TABLE 2

USE RATES: PRODUCTION TECHNOLOGIES AND WORK-ORGANIZATION PRACTICES

	Percent of Establishments		
	Any Use	Used by 50 Percent of Production Workers	Used by 100 Percent of Production Workers
Computer-aided design (CAD)	38.4	4.6	2.2
CAD linked to computer-aided machining (CAD/CAM)	22.6	2.6	.9
Numerically or computer-controlled machines (NC/CNC)	51.1	11.2	3.6
Programmable controllers (PC)	41.9	7.3	2.2
Local-area computer network (LAN)	31.6	9.5	4.4
None of the above technologies used	21.0	79.2	91.4
1 technology used	18.9	12.2	6.0
2 technologies used	20.3	4.9	1.7
3 technologies used	14.9	2.2	.4
4 technologies used	15.7	1.1	.2
5 technologies used	9.3	.4	.3
Self-directed or self-managed work teams (teams)	47.2	29.7	18.7
Job rotation	53.7	33.9	15.5
Employee problem-solving groups or quality circles (PSG/QC)	44.6	25.6	17.3
Statistical process control (SPC)	35.2	14.0	8.3
Total quality management (TQM)	42.8	29.3	24.1
None of the above practices used	12.9	33.4	52.7
1 practice used	21.9	29.3	25.5
2 practices used	22.0	18.2	12.1
3 practices used	20.1	11.9	7.0
4 practices used	14.5	5.1	2.2
All 5 practices used	8.5	2.2	.6

SOURCE: 1996 Rural Manufacturing Survey (Gale et al.) weighted for sample stratification.

of plants had 50 percent employee participation in work teams, job rotation, and TQM. Over 25 percent of plants had 50 percent employee participation in PSGs/QCs and 14 percent for SPC. By comparison, penetration rates for production technologies were low in most establishments. For example, NC was used in half of all plants, but only 11 percent of plants reported 50 percent participation with NC. Similarly, only 9.5 percent of plants had 50 percent participation in LANs, the technology with the highest penetration. Low penetration rates suggest that when production technologies are introduced, only a small portion of production workers typically use them.

Establishments varied considerably in their cumulative use of technologies and work-organization practices. Counts of technology use show that 79 percent of establishments used at least one of the production technologies, whereas 25 percent used at least four and 9.3 percent used all five technologies. Counts based on penetration show that only 20.8 percent of establishments had 50 percent of production workers involved in any of the technologies and only 8.6 percent reported 100 percent participation in one or more technologies. Since employee participation in technologies is low, we decided to use a count based on discrete use/nonuse to measure technology use in subsequent analyses in this article.

Over 87 percent of establishments used at least one work-organization practice, 23 percent used at least four, and 8.5 percent reported using all five practices. As discussed earlier, worker participation in work-organization practices is higher than participation in technologies. Two-thirds of establishments had 50 percent participation in at least one work-organization practice, and 37 percent had 50 percent participation in two or more—Osterman's (1994) criterion for a high-performance work organization. Based on these results, it seems reasonable to measure involvement in work organization by counting the number of practices in which the establishment had at least 50 percent worker participation, following Osterman.

The data also suggest that establishments with high involvement in work-organization practices are more likely to use technologies and other practices. The first column in Table 3 shows statistics for establishments with low work-organization involvement—those which did not have 50 percent worker involvement in any work-organization practices. The second and third columns show statistics for establishments with medium

TABLE 3
USE OF MANAGEMENT PRACTICES AND TECHNOLOGIES BY INVOLVEMENT IN WORK ORGANIZATION

	Number of Work Organization Practices in Which 50 Percent of Production Workers Are Involved (percent of establishments)		
Technologies and Practices Used:	None	One	Two or More
0	27	22	16
1–3	56	52	53
4–5	17	26	30
At least 3 telecommunications technologies are used	36	44	55
Research and development unit present	20	29	33
Small-batch production	23	22	22
Large-batch production	26	25	26
Custom production	34	33	30
Uses just-in-time	37	48	57
Supplies a customer that uses just-in-time	37	45	61
N (unweighted)	1135	999	1472

NOTE: Column percentages may not add to 100 due to rounding.
SOURCE: 1996 Rural Manufacturing Survey (Gale et al.) weighted for sample stratification.

(one practice) and high (two or more practices) work-organization involvement. Among establishments with high work-organization involvement, 30 percent used at least four production technologies, compared with 17 percent for establishments with low work-organization involvement. Establishments with high work-organization involvement also were more likely to use telecommunications technologies, more likely to have a research and development unit, and more likely to use JIT. However, there is no apparent difference in production method across work-organization levels.

While the data indicate a positive association between work-organization practices and technologies, there are also significant numbers of establishments that use flexible production technologies heavily, but do not use nontraditional work-organization practices, and vice versa. For example, among establishments that used none of the work-organization practices, 17 percent used at least four of the production technologies.

The Empirical Model

Since our measure of change in skill requirements is a categorical variable with ordered responses, the ordered probit model (McKelvey and Zavoina 1975; Long 1997) was adopted to estimate the underlying model in equation (1). The dependent variables take on four ordinal values corresponding to survey responses "increased a lot," "increased a little," "stayed the same," or "decreased." ("Don't know" cases were dropped from the analysis.) While we do not observe s_{jk}, the change in skill j for establishment k, we do observe the category to which it belongs. A variable Z_{jk} was constructed for the jth skill, corresponding to the ordinal survey responses:

$$Z_{jk} = \begin{cases} 3 & \text{"increased a lot"} & s_{jk} > \alpha_{3j} \\ 2 & \text{"increased a little"} & \alpha_{2j} \le s_{jk} < \alpha_{3j} \\ 1 & \text{"stayed the same"} & \alpha_{1j} \le s_{jk} < \alpha_{2j} \\ 0 & \text{"decreased"} & s_{jk} \le \alpha_{1j} \end{cases} \tag{2}$$

where α_{ij} are unobserved threshold parameters. From equation (1), it follows that the probability of a response in class i is

$$Pr(Z_{jk} = i) = \Phi(\alpha_{i+1,j} - X_k ß_j) - \Phi(\alpha_{ij} - X_k ß_j) \quad (3)$$

where Φ is the cumulative density function for the random variable e_{jk}, and $\alpha_{4j} = \infty$, $\alpha_{0j} = -\infty$. We assume that e_{jk} follows the standard normal distribution and obtain maximum-likelihood estimates of the α_{ij} and $ß_j$ parameters with an ordered probit model, as described by McKelvey and Zavoina (1975) and Long (1997). LIMDEP econometric software was used to estimate the ordered probit models in this study (Greene 1998).

The response model for establishment k is more fully specified as

$$\begin{gathered} s_{jk} = ß_{0j} + ß_{1j}T_k + ß_{2j}M_k + ß_{3j}T_k \bullet M_k + ß_{4j}TEL_k + \\ ß_{5j}SB_k + ß_{6j}SB_k \bullet T_k + ß_{7j}SB_k \bullet M_k + ß_{8j}JITU_k + ß_{9j}JITC_k + \\ \mathbf{HC}_k{}'\gamma_j + \mathbf{ESTAB}_k{}'\delta_j + e_{jk} \quad j = 1, \ldots, 6 \end{gathered} \quad (4)$$

where T_k = an index of production technology use
M_k = an index of work-organization practice use
TEL_k = an index of telecommunications practice use
SB_k = 1 if using small-batch production, 0 otherwise
$JITU_k$ = 1 if using just-in-time, 0 otherwise
$JITC_k$ = 1 if supplying a just-in-time customer, 0 otherwise
$\mathbf{HC}_k$ = a vector of human capital variables
$\mathbf{ESTAB}_k$ = a vector of variables representing establishment characteristics, e.g., size, ownership, two-digit industry codes
γ_j, δ_j = vectors of coefficients for skill j
e_{jk} = a normally distributed residual as described above

The explanatory variables are shown in Table 4 with their weighted and unweighted means.[8] If flexible manufacturing practices contribute to more rapid growth in skill requirements, the coefficients $ß_{1j}$, $ß_{2j}$, $ß_{4j}$, $ß_{5j}$, $ß_{8j}$, and $ß_{9j}$ will have positive coefficients. We are also interested in comparing the strength of the effects of the various practices across equations in order to establish empirical links between different types of practices and different dimensions of skill. For example, technology T_k may have a

[8] There is very little difference between weighted and unweighted means for most variables. However, technology and work-organization indexes have larger values when unweighted. This is so because large establishments were oversampled, and there is a strong correlation between establishment size and use of technology and work-organization practices. Other analyses of these data do not find strong differences across other strata: metropolitan-nonmetropolitan and west-nonwest (Gale et al. 1999).

TABLE 4

VARIABLE DESCRIPTIONS AND MEANS

Variable	Description	Unweighted Mean	Weighted Mean
Technologies and management practices			
Technologies	Number of production technologies used	2.31	2.18
Work organization	Number of work organization practices in which 50 percent of employees are involved	2.55	1.39
Telecommunications	Number of telecommunications technologies used	2.49	2.41
Internal JIT use	=1 if used just-in-time	.509	.482
Supplies JIT customer	=1 if supplies a customer using JIT	.518	.506
Production mode			
Small batch	=1 if produces small batches of product	.185	.232
Large batch	=1 if produces large numbers of same product	.351	.244
Custom	=1 if custom-produces products	.269	.328
Other method	=1 if uses other method	.195	.196
Worker education	Percent of production workers with		
Less than high school	Less than high school degree	19.1	20.3
High school degree	High school degree but no college	69.1	68.9
College	One or more years college	11.8	10.8
Specific vocational preparation:	Industry average share of workers requiring		
Low skill	Less than 1 month training and preparation	.158	.148
Semiskilled	1–6 months training	.402	.379
Intermediate skill	6 months to 2 years training	.124	.132
High skill	More than 2 years training	.216	.240
Plant characteristics			
Plant size	Log of plant employment	4.42	3.81
Multiunit	=1 if establishment is part of multiunit firm	.512	.346
R&D unit present	=1 if research and development unit located on site	.266	.266
Union coverage	=1 if establishment covered by collective bargaining agreement	.207	.152

SOURCE: 1996 Rural Manufacturing Survey (Gale et al.) weighted for sample stratification.

stronger association with computer skill requirements than it does with interpersonal or "soft" skill requirements. Conversely, work organization M_k may have a stronger association with interpersonal skills. We included interactions between technology, work organization, and small batch to explore the joint effects of key practices on skill requirements. MacDuffie (1995) and Ichniowski, Shaw, and Prennushi (1997) have explored the issue of complementarities among groups of management practices, suggesting that bundling may be more important than the use of individual practices. However, these studies focused primarily on the relationship between complementarity and productivity. Few studies have looked at how complementarities among practices may affect worker skills. With the exception of Bresnahan, Brynjolfsson, and Hitt (1999), previous studies also have not investigated interactions between use of technologies and management practices. The coefficients $ß_{3j}$, $ß_{6j}$, and $ß_{7j}$ will provide insight about these interaction effects.

We constructed indexes of work-organization involvement, production technology use, and telecommunications technology use using the measures discussed earlier. The work organization index ranged from 0 to 5 with a mean of 1.38. The number of production technologies used by the establishment also ranged from 0 to 5 with a weighted mean of 2.18. The number of telecommunications technologies used by the establishment ranged from 0 to 6 (although nearly all establishments used at least a fax machine) with a weighted mean of 2.41.[9]

JIT and small-batch production are practices commonly associated with flexible manufacturing, and their use may increase skill requirements by requiring greater flexibility and giving workers greater responsibility for quality control. Establishments that supply JIT-using customers may have to develop flexibility to adapt to variable demand across a large number of components, even if they do not use JIT themselves. JIT contracts often delegate primary quality control responsibility to supplying firms, and maintenance of JIT contracts is highly dependent on the supplier's ability to identify production bottlenecks and devise solutions swiftly. Our model includes indicator variables for internal use of JIT and for supplying a JIT customer. About half of establishments used JIT, and about half supplied a JIT customer. About 25 percent both used JIT and supplied a JIT customer. We also included a set of three variables that describe the establishment's mode of production. Our model includes indicator variables for small-batch, custom, and "other" production modes. Large-batch serves as the reference category.

Two measures of human capital were included in our model. As a measure of worker educational attainment, we included the establishment's percentage of production workers with less than a high school diploma and the percentage with one or more years of college. The excluded category is the share of workers with a high school diploma as their terminal degree. Cappelli (1996) found that lower educational attainment of workers was associated with an increase in generic skill requirements. However, case-study analysis suggests that the minimum requirement for traditional basic skills and capabilities in new basic skills is signaled by education beyond high school (Murnane and Levy 1996:45). A positive

[9] We experimented with a number of specifications for technology variables. The limited insight provided by more complex nonlinear specifications did not seem to warrant the greater complexity and number of coefficients to be reported that would overwhelm the reader. All specifications gave us the same general result: Skill increase is strongly correlated with use of both flexible technologies and work organization practices.

coefficient on the variable representing percentage of workers with less than a high school degree would suggest faster growth in skill requirements in plants employing less educated workers, consistent with Cappelli. A positive coefficient on the percentage of college-educated workers variable would suggest that skills are growing faster in plants that employ more educated workers.

In addition to the education variable, we used the U.S. Department of Labor's (1999) *Dictionary of Occupational Titles* (DOT) to proxy expected skill levels of workers using industry averages. The proxy reduces bias in our estimation of perceived changes in skill by providing a control for the expected level of skill intensity in an establishment. We computed the expected share of production workers in four skill classes for each three-digit manufacturing industry by merging the *DOT* with the 1996 Staffing Requirements Matrix available from the U.S. Bureau of Labor Statistics (1998). Unskilled occupations are those requiring less than 1 month of specific vocation preparation. Semiskilled occupations require 1 to less than 6 months of preparation, intermediate-skilled occupations require 6 months to 2 years, and highly skilled occupations are those requiring 2 or more years of specific vocation preparation. Industry averages were matched with survey establishments using the Standard Industrial Classification (SIC) code. We included three variables representing the share of workers in low-skilled, semiskilled, and intermediate-skilled occupations, with the share in high-skilled occupations being the excluded category. Negative coefficients on the low-skilled, semiskilled, and intermediate-skilled variables would suggest a divergence in skill levels across industries. In contrast, a positive coefficient on the intermediate-skilled variable would support Sabel's (1996) conjecture that skills are being upgraded fastest in industries characterized by a large share of intermediate-skilled workers.

The *DOT* proxies are open to some criticisms. This approach assumes that an establishment's skill level can be represented satisfactorily by the average for its industry. The *DOT* skill requirements have been criticized for being outdated, and the "representative firm" assumption may be problematic. The *DOT* skill requirements are tied to mass-production practices (Miller et al. 1980) and fail to account for the effects of new technologies and workplace organization with which this study is concerned. Despite these caveats, we find this approach preferable to the implicit assumption that the relative skill intensity of production work is invariant across detailed industries or that education alone captures differences in skills.

We include a union coverage dummy variable equal to 1 if the establishment is covered by a collective-bargaining agreement and equal to 0 otherwise. The coefficient on this variable can provide empirical evidence regarding whether skill requirements are increasing faster or slower in unionized establishments. Some observers suggest that unionized establishments have less flexibility to adopt workplace innovations. Countering this claim is evidence that the incidence of various workplace innovations in union and nonunion plants is fairly similar (Eaton and Voos 1992). The tension investigated here is that between the supposed greater "flexibility" of nonunion environments thought to facilitate the adoption of workplace innovations versus the institutional capability for "productivity bargaining" in the union setting that may be required for substantive change in the work process (see Eaton and Voos 1992). The coefficient on the union variable will provide empirical evidence regarding the relative increase in skill requirements in union versus nonunion plants.

Following Cappelli (1996), we included a dummy variable representing the presence of a research and development (R&D) unit in the establishment. A common feature of new models of production organization has been the assumption of faster rates of process innovation resulting from knowledge generated on the shop floor. Through this process, the presence of R&D facilities onsite could signal reintegration of conceptual and execution tasks for production workers, suggesting a faster increase in skill requirements, particularly in problem-solving and interpersonal/teamwork skills. As such, we expect to find a positive relationship between skills and R&D.

We include a plant-size variable (measured by log of employment) and an indicator of whether the plant is part of a multiestablishment firm as control variables. Most recently, work by Leigh and Kirk (1999) identified a positive relationship between size and branch-plant status on skill requirements of individual workers. Industry dummy variables at the two-digit SIC level are included as controls to mitigate the effect of omitted variable bias. These effects might include differences in import penetration across industries, the high-tech characterization of an industry with its higher proportion of technical, nonproduction workers, or the continual process characterization of an industry, among others.

Probit Results

Our findings suggest that our aggregate measures of high-performance work organization and technology and telecommunications use are positively associated with growth in each of the six skill requirements. However, differences in the magnitudes of the coefficients across skill equations suggest that some practices are more closely linked to certain types of skills than others. For example, the technology use coefficient was largest in the computer skills equation, whereas the strongest effect of work-organization practices was on interpersonal and problem-solving skills. The introduction of small-batch production by itself does not seem to be linked to skill increases, except in the case of computer skills. However, the coefficients on small-batch interacted with the technology and work-organization variables are positive in most equations. Supplying a JIT customer is linked to higher skills, but internal JIT use is linked to increases in only one of the six skill types. Increases in skill requirements are more common in large firms and those with multiplant facilities than in small, single-plant firms. We find mixed results in examining the human capital variables. In the rest of this section we provide further discussion of the econometric results. We discuss the signs of explanatory variables in each of the six skill equations. We then compare the effects of various practices on the predicted probabilities of increases in skill requirements. Finally, we use the predicted probabilities to provide a visual representation of the relationship between skill increases and various practices.

Model results. Table 5 reports ordered probit coefficients for each of the six skill requirements.[10] In terms of the overall strength of the models, they predict the correct category for about half the observations, considerably better than would be obtained from random chance because there are four categories. McFadden R^2 values range from 0.063 to 0.151, indicating relatively low explanatory power, but this is common for establishment-level data.

As noted earlier, both our aggregate technology and work-organization variables are associated with increases in skill requirements. The technology and work-organization variables have highly significant positive coefficients in each of the six equations in Table 5. While associations between technology use and computer skills and between work organization and interpersonal skills are not surprising, it is interesting to find that technology use is also associated with greater interpersonal skill requirements, whereas work organization is associated with greater requirements for computer and technical skills. The negative technology–work-organization interaction term in five of the six equations suggests that

[10] Coefficients for industry dummies are shown in an Appendix table.

TABLE 5

ORDERED PROBIT SKILL GROWTH REGRESSION COEFFICIENTS

Variable	Reading	Math	Problem Solving	Interpersonal	Computer	Other Technical
Constant	0.663*	0.690*	0.793*	0.500*	0.876*	1.807*
	(.163)	(.154)	(.144)	(.155)	(.170)	(.150)
Technologies and management practices						
Technology	.126*	.130*	.070*	.024*	.232*	.114*
	(.014)	(.013)	(.012)	(.012)	(.014)	(.012)
Work organization	.138*	.113*	.250*	.304*	.155*	.193*
	(.025)	(.022)	(.019)	(.021)	(.021)	(.019)
Technology × work organization	–.018*	–.002	–.022*	–.033*	–.034*	–.021*
	(.007)	(.006)	(.005)	(.006)	(.006)	(.005)
Telecommunications	.121*	.118*	.173*	.170*	.208*	.081*
	(.016)	(.014)	(.013)	(.014)	(.014)	(.012)
Internal JIT use	.054+	–.037	–.109*	.031	–.111*	–.095*
	(.031)	(.028)	(.027)	(.026)	(.027)	(.026)
Supplies JIT customer	.139*	.262*	.270*	.129*	.130*	.289*
	(.030)	(.027)	(.028)	(.028)	(.028)	(.028)
Production mode						
Small batch	–.184*	–.099	.003	–.011	.353*	.029
	(.071)	(.070)	(.061)	(.060)	(.061)	(.059)
Small batch × work organization	.142*	.108*	.074*	.090*	.030	.098*
	(.026)	(.029)	(.026)	(.024)	(.024)	(.023)
Small batch × technology	.047*	.018	.036+	.143*	–.032+	–.006
	(.023)	(.021)	(.021)	(.018)	(.019)	(.017)
Custom	–0.72+	–.099*	.237*	.184*	.189*	.162*
	(.042)	(.040)	(.038)	(.038)	(.038)	(.038)
Other method	–.066	–.051	.006	.061	.279*	.220*
	(.046)	(.041)	(.041)	(.041)	(.041)	(.040)
Large batch (excluded)						
Worker education						
Less than high school	.0027*	–.0004	.0012*	–.00002	.0016*	.0005
	(.0006)	(.0005)	(.0005)	(.0005)	(.0005)	(.0005)
College	.0011*	.0006	–.0002	.0011*	.0114*	.0018*
	(.0004)	(.0005)	(.0003)	(.0004)	(.0008)	(.0003)
High school (excluded)						
Specific vocational preparation						
Low skill	1.300*	.900*	–.660*	–.151	.780*	–.240*
	(.224)	(.203)	(.166)	(.193)	(.197)	(.193)
Semiskilled	.445*	.533*	.043	.499*	.134	–.540*
	(.187)	(.177)	(.168)	(.171)	(.171)	(.023)
Intermediate skill	1.628*	1.349*	.867*	1.491*	.823*	–1.186*
	(.314)	(.281)	(.289)	(.285)	(.294)	(.161)
High skill (excluded)						
Establishment characteristics						
Plant size	0.69*	.054*	.157*	.262*	.021	.063*
	(.019)	(.015)	(.018)	(.019)	(.018)	(.019)
Multiunit plant	.162*	.134*	.132*	–.044	.032	–.005
	(.038)	(.033)	(.033)	(.035)	(.033)	(.032)
R&D unit present	–.040	.057+	.112*	.100*	–.035	.114*
	(.035)	(.033)	(.033)	(.032)	(.031)	(.033)
Union coverage	.211*	.019	.028	.023	.058	.070+
	(.046)	(.043)	(.044)	(.040)	(.040)	(.041)
Correct predictions	.545	.503	.470	.505	.486	.489
McFadden R^2	.151	.097	.077	.086	.115	.063

NOTE: Ordered probit equations were estimated separately for each skill type using LIMDEP. Industry dummy variables are reported in an Appendix table. *Significant at 0.05. + significant at 0.10. $N = 2997$. Estimated from 1996 Rural Manufacturing Survey.

technologies and work organization may to some degree measure the same latent characteristic of modernization that affects skill demands. However, in calculations not shown here, we found that the net effect of the work-organization and technology variables on skills remained positive because the interaction effects were quite small.

The telecommunications variable is positive and significant in each equation, indicating that use of telecommunications technology has a positive association with skill growth. This strong association with production worker skills is particularly interesting because telecommunications technologies are used primarily by nonproduction workers. To the extent that telecommunications technologies are used to increase responsiveness to customers, the results suggest that greater interconnectivity with other firms may increase skill requirements.

Supplying a JIT customer is positively associated with growth in all six skills, but internal use of JIT is positively associated with only one skill. It is interesting to note that JIT appears to have a greater impact on skill requirements in JIT-supplying firms than in JIT-using firms. The strong effect of JIT supply on skill requirements is consistent with the notion that JIT relationships demand greater flexibility and quality control from supplying firms. Removing inventory as a reserve against contingency may heighten "learning by monitoring" requirements in JIT-supplying firms that must identify production bottlenecks and swiftly devise permanent solutions to maintain JIT contracts (Sabel 1994).

Small-batch production had a significant positive coefficient only in the computer skills equation. However, small-batch had a number of significant positive interactions with work organization and technology, supporting arguments regarding the more progressive variant of this production mode (Piore 1990). The small-batch–work-organization interaction coefficients are positive and significant in five equations, and the small-batch–technology coefficient is positive and significant in three equations. The positive interactions suggest that skill requirements are increasing only in small-batch plants where the technologies and work-organization practices examined in this study are in use.[11]

The coefficients in Table 5 shed light on the association between skill requirements and two measures of human capital, as well as on unionization, establishment size, and ownership. The links between skill increases

[11] Small-batch production was most common in the instruments and electrical equipment industries, where about 30 percent of establishments used small-batch. Large-batch production was used by about 30 percent of establishments in most two-digit industries but was most prevalent in food processing, textiles, apparel, and petroleum processing. Custom production was most common in paper products, printing, and industrial machinery, where over 40 percent of establishments used custom production.

and the human capital variables are mixed. The reference category for the education variables is the percentage of production workers with a high school degree but no college. The coefficients suggest that establishments with less educated workers had faster growth in problem-solving skills, whereas those with more college-educated workers reported more growth in other technical skills. In the reading and computer skills equations, both the less than high school and college variables had positive coefficients, suggesting that establishments with concentrations of low- and high-educated workers experienced faster growth in reading and computer skills than those which employed mostly high school graduates.

The specific vocational preparation variables (as measured by *DOT*) also had differing effects across equations. For three skill types (computer, interpersonal, and problem solving), the vocational preparation effects seem to be strongest for establishments in industries characterized by a large share of intermediate-skilled workers (6 months to 2 years of preparation). This is consistent with Sabel's (1996) argument that intermediate-skilled workers (those who possess a contextual understanding of the work process yet lack expertise in technical skills required of craft occupations) may experience the greatest increase in problem-solving and interpersonal skill requirements. The positive coefficients for the low-skilled, semiskilled, and intermediate-skilled worker shares in the reading and math equations suggest that reading and math skills grew faster for establishments in industries characterized by a large share of low- to intermediate-skilled workers. This may suggest the importance of remedial training in basic academic skills in industries that traditionally are low- and semiskilled-intensive. Conversely, the fact that negative coefficients for low skilled, semiskilled, and intermediate skilled share variables in the "other technical skills" equation suggests that growth in technical skill demand was faster for establishments in industries that employ a greater share of high-skilled workers. A surprising result is the positive association between low-skilled industry worker shares and computer skill requirements. This suggests that computer skill requirements are growing rapidly in industries with low-skilled workers. This contrasts with the frequent assumption in the literature on earnings inequality that computer use is associated with skilled workers.

Faster growth in skill requirements is positively associated with establishment size for five of the six skill types. Multiunit firms are associated with faster growth in reading, math, and interpersonal skills but slower growth in other technical skills. Leigh and Kirk (1999) found similar associations between establishment size and multiunit status. Unionized establishments tended to report faster growth in reading and other technical skill demands, but there was no association between unionization and the other four skill types. The presence of an R&D unit was positively associated with growth in math, interpersonal, problem-solving, and other technical skills. This result is consonant with the greater integration of conception and execution in production operations suggested by Sabel (1996).

Magnitude of effects. To aid in the interpretation of the results, we used the probit estimates to compute the change in probability associated with discrete changes in technology and management practice variables while holding other variables constant. The magnitude of the various probit coefficients cannot be compared directly because the probability of skill increase is a nonlinear function of the explanatory variables. We computed changes in predicted probabilities resulting from discrete changes in the values of each explanatory variable, as recommended by Long (1997:135–8). We began by computing the predicted probability of rapid increase in each skill given a base case where technology, work organization, telecommunications, small batch, custom production, other production methods, internal use of JIT, supplying JIT customers, and presence of an R&D unit were set to 0. Other variables were set to their mean values.[12] We then alternately changed each variable's value (while holding other values constant) and computed the new predicted probability. For example, to compute the discrete effect D_j on the probability that skill j "increased a lot" associated with an increase in technology use from 0 to 2 practices, we calculated

$$D_j = P(Z_j = 3 \mid b_j, X_B, T = 2) - P(Z_j = 3 \mid b_j, X_B, T = 0) \qquad (5)$$

where $Z_j = 3$ indicates that skill j "increased a lot," b represents the estimated probit coefficients for equation j, X_B is the base case, and T is the number of technologies used. To compute discrete effects on the skill increase probabilities, we increased the technology, work-organization, and telecommunications variables alternately from 0 to 2. The small-batch, custom, other production methods; internal JIT use; JIT customer; and R&D variables alternately were set to 1 because they are dummy variables. While technology and work organization were both significant

[12] For example, the model for reading skills predicts that an establishment with these base values would have a 2.3 percent chance of reporting a rapid increase in reading skills, a 9.6 percent chance of reporting "some increase," an 84.8 percent chance of reporting "no change," and a 3.4 percent chance of reporting a "decrease."

in each equation, the strength of association varied across equations in the expected manner. Reading across the first line of Table 6, it is clear that technology is most strongly associated with computer skill increases. The probability of rapid increase in computer skills rises by 8.1 percentage points as the number of technologies is increased from 0 to 2, whereas the effects on the other five types of skill are 1.7 percentage points or less. In accord with expectations, the effect of technology on interpersonal skills is weakest (though it is statistically significant), at only 0.6 percentage points. The effect of increasing work-organization practices from 0 to 2 is largest for interpersonal skills, at 11.7 percentage points. In contrast to the technology effects, work organization is strongly associated with growth in a broader set of skills. While the effect on interpersonal skills is clearly the largest, the associations of work organization with problem-solving (6.8 percentage points), computer (4.9 percentage points), and other technical skills (3.1 percentage points) are also relatively large. The associations of both technology and work organization with growth in reading and math skills are similar—less than 2 percentage points.

Effects of telecommunications are similar to those of technology for four of the six skills. The strongest association of telecommunications is with computer skill growth (7.1 percentage points). Telecommunications also has a strong association with interpersonal (5.5 percentage points) and problem-solving skills (4.2 percentage points). Telecommunications has weaker (but statistically significant) effects of less than 2 percentage points in the reading, math, and other technical skills equations.

Effects of other practices generally were weaker. The strongest effect of the JIT customer variable was in the problem-solving skills equation (3.1

TABLE 6

DISCRETE EFFECTS OF TECHNOLOGY AND MANAGEMENT PRACTICE USAGE ON THE PROBABILITY THAT SKILL REQUIREMENTS "INCREASED A LOT"

	Percentage Points					
Practice	Reading	Math	Problem	Interpersonal	Computer	Technical
Technologies=2	1.7	1.7	1.4	0.6	8.1	1.6
Work organization practices=2	1.9	1.4	6.8	11.7	4.9	3.1
Telecommunications=3	1.7	1.5	4.2	5.5	7.1	1.1
Internal JIT use	0.3	*n*	–0.9	*n*	–1.3	–0.5
Supplies JIT customer	0.9	1.7	3.1	1.8	1.8	2.1
Small-batch production	–0.8	*n*	*n*	*n*	5.7	0.2

n = probit coefficient not significantly different from zero.

NOTE: Table shows difference in predicted probability of establishment reporting that skill "increased a lot" compared with predicted probability for a base case. In the base case, technology, work organization, telecommunications, JIT use, JIT customer, small batch, custom production, other production methods, and R&D unit variables set to 0; other values were set to mean values. Predicted probabilities were computed from coefficients in Table 5.

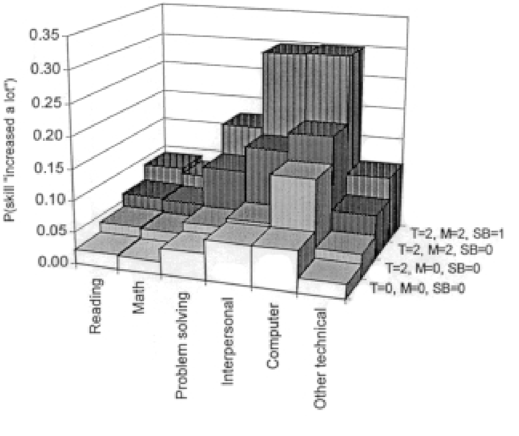
percentage points). The JIT customer variable's effects in other equations ranged between 0.9 and 2.1 percentage points. As noted earlier, JIT use had a positive effect only on reading skills, and the magnitude of the effect was small (0.3 percentage points). The effects of small-batch and R&D unit variables generally were about 1 percentage point or less. The exception is the relatively large 5.7 percentage point effect of small-batch on the probability of rapid computer skill growth. While the direct association of small-batch with the other five skill types is weak or not significant, small-batch has important positive interaction effects, as noted earlier.

Finally, we use the predicted effects estimated in Table 6 to illustrate how skill requirements increase with the cumulative adoption of the various practices. Figure 1 provides a graphic representation of how growth in skill requirements responds to various combinations of practices. It shows the predicted probability that each of the six skills "increased a lot" for four scenarios. The first scenario is one where none of the practices are used. The technology, work-organization, telecommunications, JIT use, JIT customer, small-batch, and other variables were all set to 0, with other explanatory variables set to their mean values. For this base case, predicted probabilities of rapid increase in skill requirements are low for each of the six skills, ranging from about 2 percent for reading and math skills to about 7 percent for interpersonal and computer skills. Adding two technologies while holding work organization and small-batch at 0 increased the probability of rapid increase for each skill, but the increase was largest for computer skills. In the third scenario, the number of

FIGURE 1

PREDICTED PROBABILITIES THAT SKILL "INCREASED A LOT" BY TECHNOLOGY AND MANAGEMENT PRACTICE USE

(Note: Predicted values were computed from coefficients in Table 5. Custom production, other production methods, and R&D unit variables set to 0; other variables were set to mean values.)



work-organization practices was increased to 2, whereas the number of technologies remained at 2 with no small-batch production. Thus this third scenario reflects moderate use of work organization and technologies without small-batch production. A comparison of the probabilities associated with the second and third scenarios indicates a greater likelihood of rapid increase for each skill type when two work-organization practices were added, but the change in probability was greatest for interpersonal and problem-solving skills. This reflects the large magnitude of the effect of work organization on those two skills. The probability that computer and other technical skill requirements "increased a lot" also rose by several percentage points, whereas the effect on reading and math skills was more modest. In this third scenario, there was growth in a broader set of skills, although computer skills were still the most likely to grow. In the fourth scenario, small-batch production was added. The probabilities associated with this scenario illustrate the large interaction effects of small-batch with technology and work organization. The incremental effect of small-batch when work-organization practices and technology are in use was particularly large for interpersonal and computer skills. In this fourth scenario, interpersonal and computer skills stand out together as the most likely to be reported as increasing rapidly.

Discussion and Conclusions

There has been much concern over whether use of new technologies increases demand for technical skills, resulting in a wider wage gap between those who do or do not have needed skills and an erosion of industrial competitiveness if the supply of skilled workers is inadequate. However, the focus on technical skill may be overly narrow. New decentralized "flexible" methods of production coordination may be raising demands for a broader set of skills. Decentralized approaches shift emphasis from production engineering to work groups and give greater autonomy to basic production units, potentially boosting demands for nontraditional problem-solving and teamwork skills. A number of case studies have suggested demand for a broader set of skills associated with new management practices, but little statistical evidence has been available previously.

Our study explored the empirical link between increases in six types of worker skill requirements and a broad range of new technologies and management practices using a large sample survey of manufacturing establishments. We were able to examine a set of six worker skill requirements that broadly correspond to the set of "new basic skills" identified by authors such as Murnane and Levy (1996) and Applebaum and Batt (1994). We examined difficult-to-quantify interpersonal/teamwork and problem-solving skills as well as computer and basic academic (reading and math) skills. We found that greater use of flexible technologies and work-organization practices was positively linked to reported increases in each of six skill requirements. Use of new work-organization practices had an especially strong association with problem-solving and interpersonal/teamwork skill requirements, whereas production technology use was most strongly associated with increases in computer skill requirements. Use of high-performance work-organization practices also appeared to be linked to a broader set of skill requirements. We found that the link between skill demands and work organization and production technologies was even stronger when those practices were used jointly with small-batch production. Other novel results include our findings that skill requirements rose faster in establishments that used telecommunications technologies and establishments that supplied other firms using JIT. However, internal use of JIT was not strongly linked to growth in skill requirements.

The employers in our survey reported growth in computer, interpersonal/teamwork, and problem-solving skill requirements most frequently, but it is important to recognize that requirements for traditional academic skills are also growing. Indeed, to the extent that technical, problem-solving, and "soft" skills are derivative of a sound foundation in numeracy and literacy, this result is to be expected. The similarity of the effects on both reading and math skills across the technology, work-organization, and telecommunications variables is striking. Murnane and Levy (1996) suggested that the ninth grade level of proficiency in reading and math is a minimum floor required of good jobs, although many good jobs will require greater skills. However, we could not determine whether greater skill requirements were remedial or an augmentation beyond this minimum because we lacked information on reading and math aptitudes of production workers in the plants in our survey.

The results of this study demonstrate a strong association between manufacturing modernization variables and increasing requirements across the range of new basic skills. The strong empirical link between flexible practices and interpersonal/teamwork and problem-solving skills suggests that workers well prepared in basic academic skills may still lack important skills sought by cutting-edge employers. This has important implications for academic and vocational training programs where basic academic and computer skills are often emphasized. Skill-development policy must recognize the diversity of skills demanded by employers

(Howell and Wolff 1992) and that some of the most sought skills infrequently are taught in academic and job training programs.

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APPENDIX

TABLE A.1

ESTIMATES OF TWO-DIGIT SIC CONTROLS

Variable	Reading	Math	Problem Solving	Interpersonal/ Teamwork	Computer	Other Technical
SIC 22	0.654*	0.171	–0.151	–0.378*	0.246	0.081
	(.175)	(.165)	(.133)	(.119)	(.180)	(.136)
SIC 23	–0.301	–0.379	–0.297*	–0.584*	0.084	–0.300*
	(.211)	(.218)	(.116)	(.108)	(.106)	(.114)
SIC 24	0.105	0.207*	–0.065	–0.235*	0.115	0.022
	(.125)	(.099)	(.088)	(.100)	(.088)	(.095)
SIC 25	–0.216	–0.338*	–0.672*	–0.652*	0.079	–0.179
	(.201)	(.151)	(.115)	(.123)	(.144)	(.137)
SIC 26	.0262*	–0.148	0.251*	0.198*	0.306*	0.006
	(.101)	(.101)	(.092)	(.092)	(.096)	(.090)
SIC 27	0.0004	–0.150*	–0.068	0.020	0.812*	0.188*
	(.083)	(.068)	(.065)	(.065)	(.071)	(.067)
SIC 28	–0.106	–0.148+	–0.185*	–0.031	0.371*	–0.182+
	(.102)	(.085)	(.069)	(.085)	(.077)	(.094)
SIC 29	–0.062	–0.821*	–0.901*	–1.050*	0.500*	–0.045
	(.248)	(.218)	(.118)	(.129)	(.203)	(.298)
SIC 30	0.205*	–0.286*	–0.242*	–0.241*	–0.118	–0.084
	(.101)	(.091)	(.079)	(.082)	(.081)	(.087)
SIC 31	–0.026	–0.694	–0.354	–0.497	–0.088	0.100
	(.879)	(1.090)	(.732)	(.785)	(.872)	(.882)
SIC 32	0.657*	0.099	–0.095	–0.177	0.234*	–0.014
	(.109)	(.126)	(.099)	(.111)	(.103)	(.123)
SIC 33	0.542*	0.193*	0.034	–0.004	0.364*	0.336*
	(.103)	(.085)	(.084)	(.086)	(.090)	(.082)
SIC 34	0.520*	0.348*	–0.261*	–0.110	0.410*	0.087
	(.092)	(.074)	(.072)	(.072)	(.074)	(.076)
SIC 35	0.248*	–0.148+	–0.250*	–0.305*	0.508*	–0.021
	(.105)	(.084)	(.076)	(.083)	(.084)	(.084)
SIC 36	0.253*	–0.151+	–0.434*	–0.447*	0.143+	0.180*
	(.109)	(.091)	(.083)	(.084)	(.085)	(.086)

SIC 37	0.269*	–0.007	–0.190*	–0.420*	0.118	–0.005
	(.121)	(.104)	(.087)	(.089)	(.099)	(.097)
SIC 38	0.357*	0.007	–0.346*	–0.390*	0.378*	–0.042
	(.107)	(.090)	(.082)	(.087)	(.088)	(.092)
SIC 39	–0.150+	–0.465*	–0.169*	–0.044	–0.065	–0.236*
	(.086)	(.072)	(.072)	(.065)	(.068)	(.067)

NOTE: Table shows ordered probit coefficient estimates for industry dummy variables for equations shown in Table 5. $N = 2997$. SIC 20 is the excluded category.

*Significantly different from zero at 0.05. + significantly different from zero at 0.10. Estimated from 1996 Rural Manufacturing Survey data.